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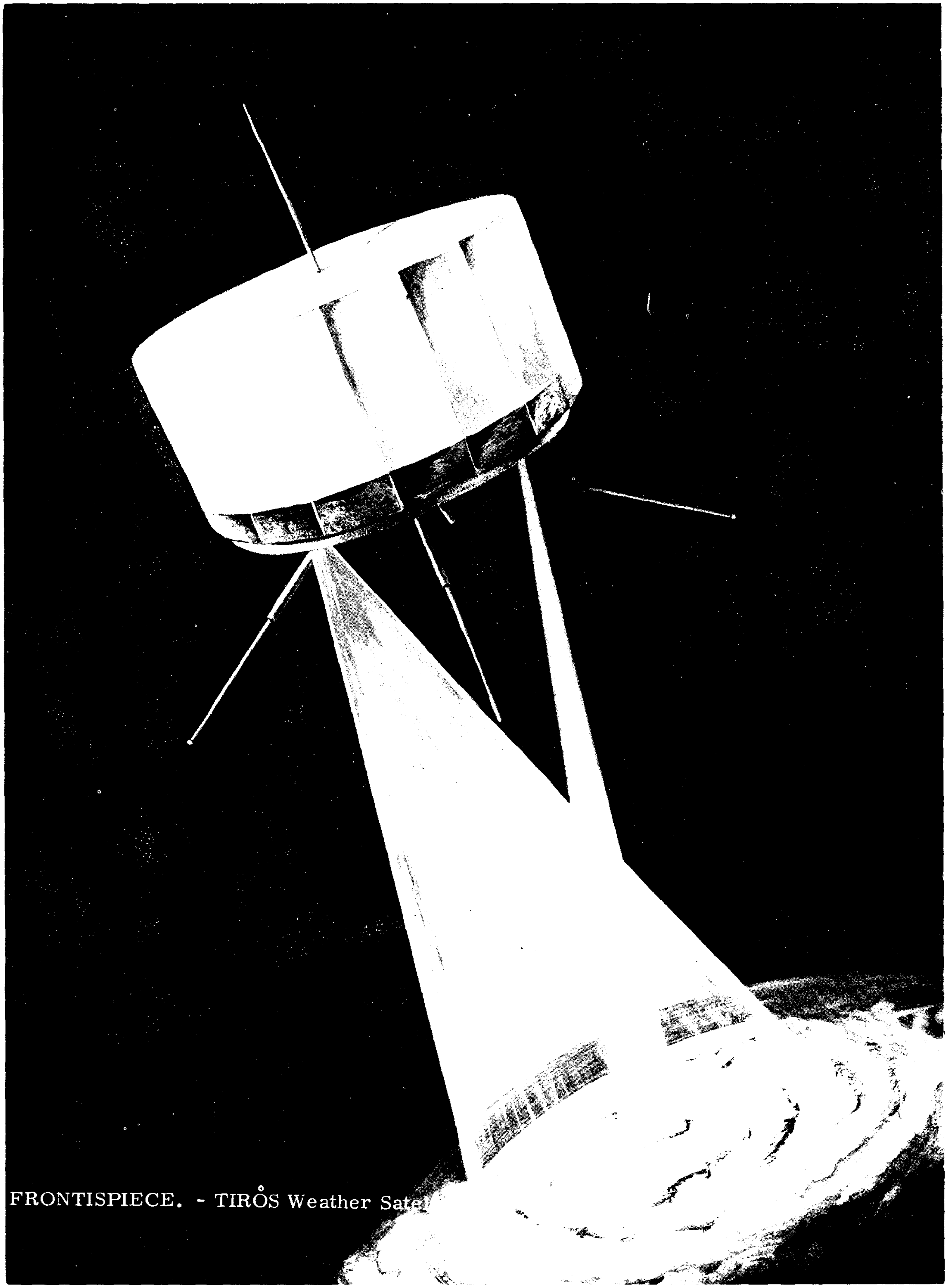
OPERATIONAL USE

of

WEATHER SATELLITES

U. S. NAVY WEATHER RESEARCH FACILITY
NORFOLK, VIRGINIA

March 1960



FRONTISPIECE. - TIROS Weather Sate

Preliminary Report on Task 33

Operational Use of WEATHER SATELLITES

APPLIED RESEARCH
A-R-O-W-A
OPERATIONAL WEATHER ANALYSIS

U. S. NAVY WEATHER RESEARCH FACILITY
BUILDING R-48
U.S. NAVAL AIR STATION
NORFOLK 11, VIRGINIA

March 1960

FOREWORD

In July 1959, while planning for the first meteorological satellite was nearing completion, Task 33, "Meteorological Satellite Analysis Techniques", was assigned to the Navy Weather Research Facility by the Bureau of Aeronautics. At that time there were virtually no data from which to initiate a study of weather satellite techniques, and even as this publication goes to press, the scheduled date for launching TIROS (Television and Infrared Observation Satellite), the first true meteorological satellite, is still in the future.

The Navy Weather Research Facility has spent the past six months in studying the general characteristics of satellites and in attempting to determine how significant features of the weather map (e.g., cyclones, frontal zones, hurricanes, easterly waves, etc.) will appear in the data received from the first meteorological satellite.

In this report Mr. Robert Fenn, Task Leader of Task 33, discusses various aspects of meteorological satellites and shows, by comparing photographs taken from a ballistic missile at great heights with an analyzed weather chart, one type of meteorological data which may be expected from operational satellites of the future.

Daniel F. Rex

DANIEL F. REX
Commander, U. S. Navy
Officer in Charge
U. S. Navy Weather Research Facility

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SUMMARY

This is the first report on Task 33 "Meteorological Satellite Data Analysis Techniques". The information contained herein is a result of research conducted during the initial pre-launch phase of Project TIROS (for Television and Infrared Observation Satellite), the NASA - sponsored meteorological satellite, tentatively scheduled for launch during late March or early April 1960. This satellite will provide only cloud-cover data.

The preliminary report is limited to (1) a brief description of meteorological satellites in order to provide background information to forecasters, who may eventually use the data received from them; (2) a discussion of some of the fundamental relationships between clouds and weather; and (3) a hypothetical case-study, showing how cloud-cover analysis can be used to supplement surface observational data in preparing an operational forecast.

Photographs taken from an Atlas missile at an altitude of approximately 400 miles, were used to simulate TV images from a satellite.

1. WEATHER OBSERVATIONS FROM EARTH SATELLITES

1.1 Introduction

Considerable progress has been made in classical and theoretical meteorology during the past 40 years. The most promising development in recent years has been the adaptation of high speed electronic computers to the problems of weather forecasting. Numerical methods have created a demand for more observational data, but recent studies of the relationship of data density to forecast accuracy indicate that little improvement is brought about by the increase in data density beyond a critical value (33). This critical value is available in most existing land networks in the Northern Hemisphere, but there are still many parts of the world where no weather observations are made. Nearly three-fourths of the globe lies within this silent area. Placing adequate weather observatories in all of these regions would be an impossible task.

Perhaps the chief reason that the increase in our meteorological knowledge has not been accompanied by a corresponding improvement in forecasting still lies in the fact that forecasting methods are still largely empirical and dependent upon experience, and appear likely to remain so for many years.

The atmosphere is a vast and complex machine and present methods of gathering data give only fragmentary glimpses of small portions at a time. For the forecaster to piece these fragments together is somewhat analogous to attempting to visualize the workings of a gasoline engine by glancing at parts of the carburetor. Artificial satellites equipped with weather observing instruments appear to offer the best means for obtaining an integrated picture of the entire atmosphere.

1.2 Capabilities of Meteorological Satellites

''From a satellite the forecaster would have a ''birds-eye view'' of the whole earth, and as the satellite swung around in its orbit, he would be able to see everything he wanted. Whole meteorological systems would be spread out for his inspection, and although he would still have to depend upon ground stations to some extent, it would not be long before the behavior of the atmosphere became really understood. It

might even be possible to predict long-range climate for various latitude zones of the earth and for various seasons."*

"One of the greatest advances in the field of meteorology will take place when man will be able to make more or less continuous observations of the earth from a station far above the surface of the earth. No other technique could possibly do what will ultimately be possible from a satellite. With photography or television or an observer at 2,000 miles altitude, an area equal to the United States synoptic chart published by the Weather Bureau would be visible. Then tropospheric weather systems in their entirety could be tracked by means of their associated clouds. The generation, growth and course of "bad-weather" systems such as hurricanes will undoubtedly be observable.

"Detailed photographs of the clouds may make possible studies of the topographic features that give rise to the so-called "orographic" clouds and of special phenomena such as thunderstorms and, possibly, tornadoes that are revealed through their unique cloud formations. These studies could well give information on the origin, growth, and course of such events and on their related properties - pressure, temperature gradients, vortex slopes, etc."**

A satellite placed in a circular polar orbit at an altitude of 350-400 miles would make 15 orbits, covering the entire earth's surface, once every 24 hours. At an altitude of 4,000 miles it would view one-fourth of the earth's surface. At 22,000 miles, over the Equator it would view more than one-third the earth's surface and provide a permanent observatory fixed in space. Three such satellites in orbits 120° apart would provide total world coverage for an indefinite period (21).

1.2.1 Observations from Meteorological Satellites

1.2.1.1 Visual Observations

*Patrick Moore, FRAS, Director of the Mercury and Venus section of the British Astronomical Association and Fellow and Council Member of the British Interplanetary Society (Earth Satellites).

**W. G. Stroud and W. Nordberg in "Scientific Uses of Earth Satellites" edited by James Van Allen.

TV cameras will provide cloud cover data for climatological purposes and information about wind shear, jet streams, and structure and movement of major weather systems. Estimates of horizontal and vertical motion may be made from carefully analyzed cloud photographs. In general, cloud cover data will be most useful when integrated with data obtained by conventional means.

1.2.1.2 Radiometric Observations

Infrared sensors, when coordinated with TV pictures, may provide data on the following:

(a) Surface temperatures.
(b) Temperatures at or near the tropopause.
(c) Height or thickness of atmospheric layers.
(d) Moisture content.
(e) Albedo (clouds).
(f) Energy balance data.
(g) Ozone content.

1.2.1.3 Radar Observations

Radar sensors will supplement data obtained from surface stations and aircraft, and furnish additional information on the extent and intensity of clouds and weather systems.

1.2.1.4 Sferics Observations

These would supplement data obtained from a very limited number of surface stations and might prove valuable in the investigation of tornadoes and other severe storms.

Some of the measurements proposed for meteorological satellites are shown in figure 1.1.

The currently planned meteorological satellite (TIROS, Television and Infrared Observation Satellite) will provide only visual observations.

1.3 Optimum Orbits for Meteorological Satellites

The simplest orbit, a circular one, appears most suitable for

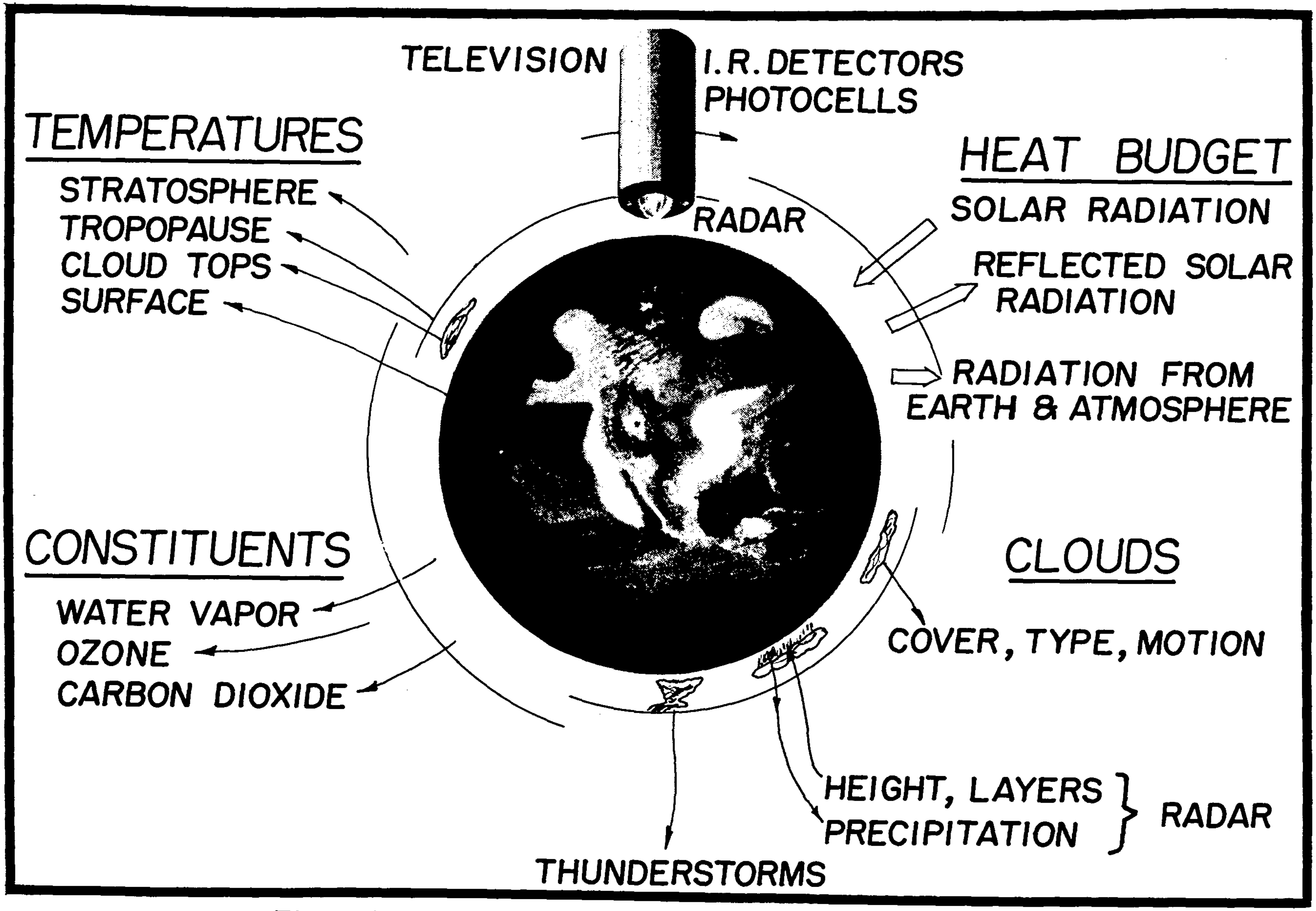
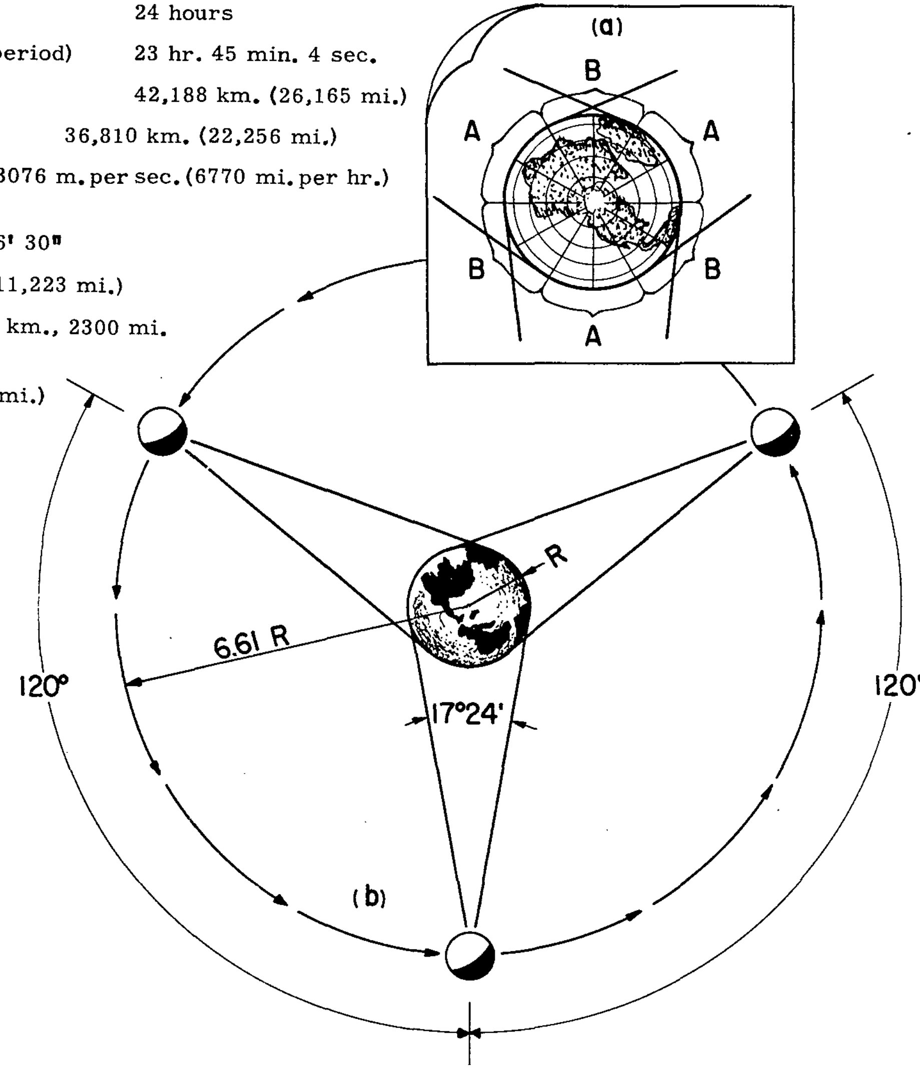


Figure 1.1. Measurements with Meteorological Satellites.

Period of rotation relative to the sun (solar period)	24 hours
Period of revolution with respect to the celestial sphere (sidereal period)	23 hr. 45 min. 4 sec.
Distance from center of the earth	42,188 km. (26,165 mi.)
Altitude above Equator	36,810 km. (22,256 mi.)
Circular velocity	3076 m. per sec. (6770 mi. per hr.)
Length of arc of Equator from which artificial satellite is visible and which is visible from satellite	162° 36' 30"
Same arc in units of length	18,102 km. (11,223 mi.)
Arc of Equator not covered by two satellites	34° 47', 3872 km., 2300 mi.
Total length of arc on Equator from which two of three equidistant satellites would be visible	14,232 km. (8,823 mi.)
Length in percent of total length of Equator	26.21



For Simultaneous Observations of the Entire Circumference of the Earth by the Aid of Artificial Satellites, at Least Three Such Satellites are Necessary. (a) A(77° 21') One Satellite Visible, B(42° 39') Two Satellites Visible; (b) - Stationary Orbit 3076 meters per second (6770 mi. per hr.)

Figure 1.2. The 24-Hour Satellite.

meteorological purposes. Scientists are far from agreed on an optimum altitude or trajectory, but a polar orbit has a decided advantage in that it provides greatest coverage.

Some orbits which have been suggested are shown below:

Height in Miles	Period of Orbit
200	90 min.
400	99.6 min.
1,000	2 hr.
22,000	24 hr.
235,000	1 lunar month.

1.3.1 The 24-Hour Satellite

The satellite with a period exactly that of the earth is of special interest, particularly to meteorologists. If placed over the Equator, moving eastward in its orbit, it would appear to remain always at the same point in space, as viewed from the earth. Such a satellite would have in view, at usable angles of incidence, about 38.2 percent of the earth's surface, or approximately 75 million square miles as shown in figure 1.2.

1.4 Limitations

Meteorologists have not shown as much enthusiasm for satellites as have other scientists, possibly because obtaining usable meteorological data presents rather serious problems.

1.4.1 Resolution

Resolution is a term originally used by astronomers to specify the ability of a telescope to separate double stars. As applied to photographs, it refers to the capability of the entire photographic system, including lens, exposure, processing, and other factors to render a sharply defined image. It is usually expressed as the maximum number of lines per millimeter that can be resolved or seen as individual lines. Ground resolution, expressed in ground-size equivalent to one line, is generally used in discussing performance of cameras (28). The meteorological utility of various resolution capabilities in miles is shown in figure 1.3.

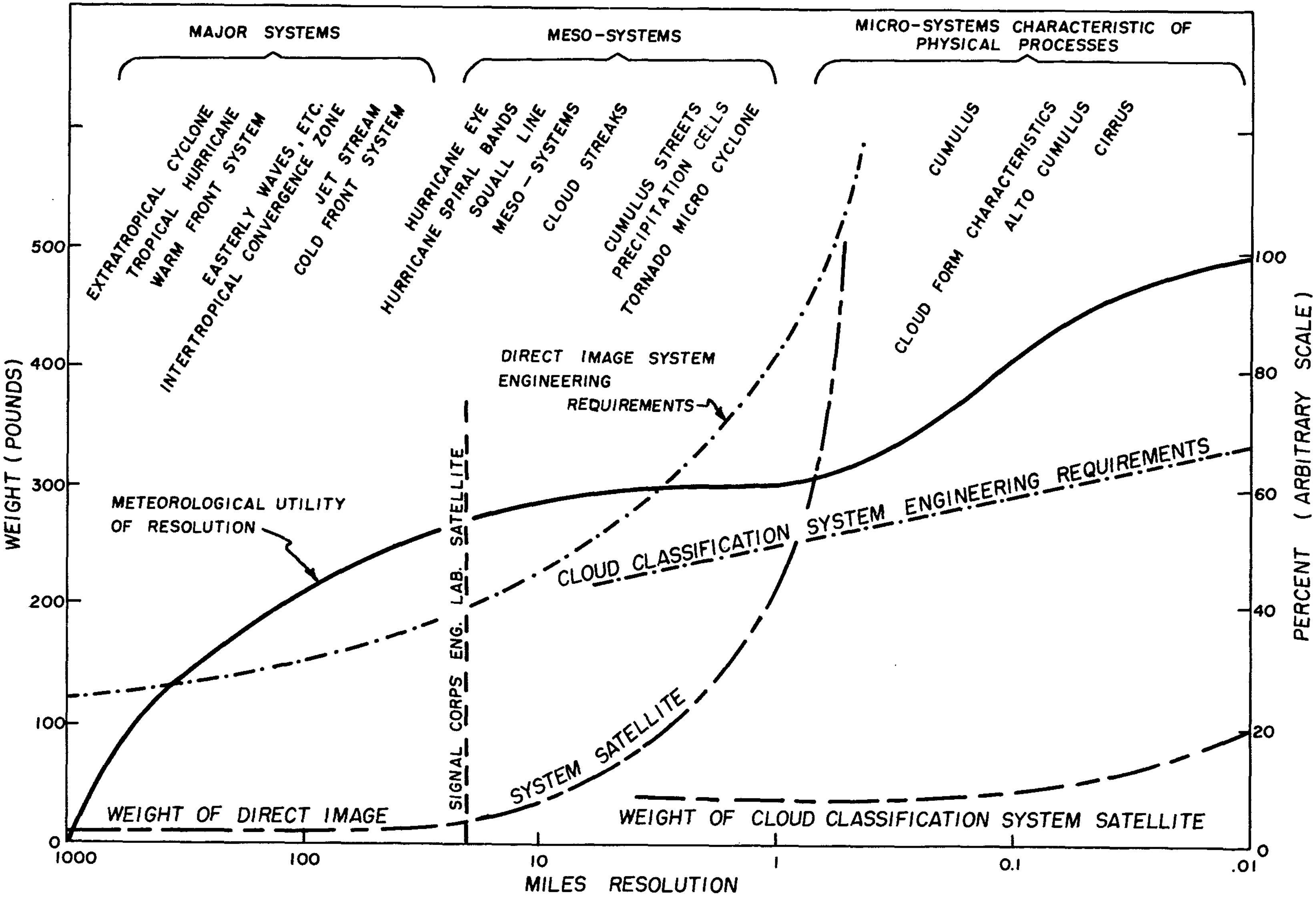


Figure 1.3. Estimates of Meteorological Utility, Weight, and Engineering Requirements of Various Resolution Capabilities.

1.4.2 Distortion and Image Quality

Pictures taken with a wide-angle lens are subject to distortion around the edges. Image quality usually deteriorates in a narrow-angle lens because of decreased depth perception and difficulties encountered in absorbing vibration and image motion in the mounting system (28).

1.4.3 Orientation

For forecasting purposes location accuracy of significant weather features within 50 miles is desirable (11). In many cases recognizable features of the earth's surface will be sufficient for orientation. But in ocean areas large cloud masses may obscure landmarks and make such a degree of accuracy impossible in what may be an area of greatest interest. Where a horizon appears on the image, location can be made by use of a precomputed grid system. When a horizon is not visible orientation is still possible, although considerably more difficult. Unless significant meteorological features are immediately apparent from the photograph, the additional computations required may not be justified for operational use.

If direct readout at forecast centers becomes feasible it seems probable that experienced forecasters will learn to locate significant weather features on satellite photographs and correlate them with supplementary data on the usual meteorological charts, without the presently necessary intermediate steps.

1.4.4 Rectification (Grids)

Grid systems developed for the TIROS meteorological satellite (fig. 1.4) are based on the ''Canadian Grid''. Although reduction of the data must usually be done by a computer, it is a comparatively simple grid to construct and use. Some distortion and loss of accuracy occurs near the horizon in transferring the photographic image to a flat surface. An added disadvantage is that data must usually be transferred from the grid to a transverse mercator chart before it can be plotted on a weather chart - usually a polar stereographic or Lambert conformal projection on a different scale.

1.4.5 Coverage

A circular orbit of 350-400 miles appears to be the present

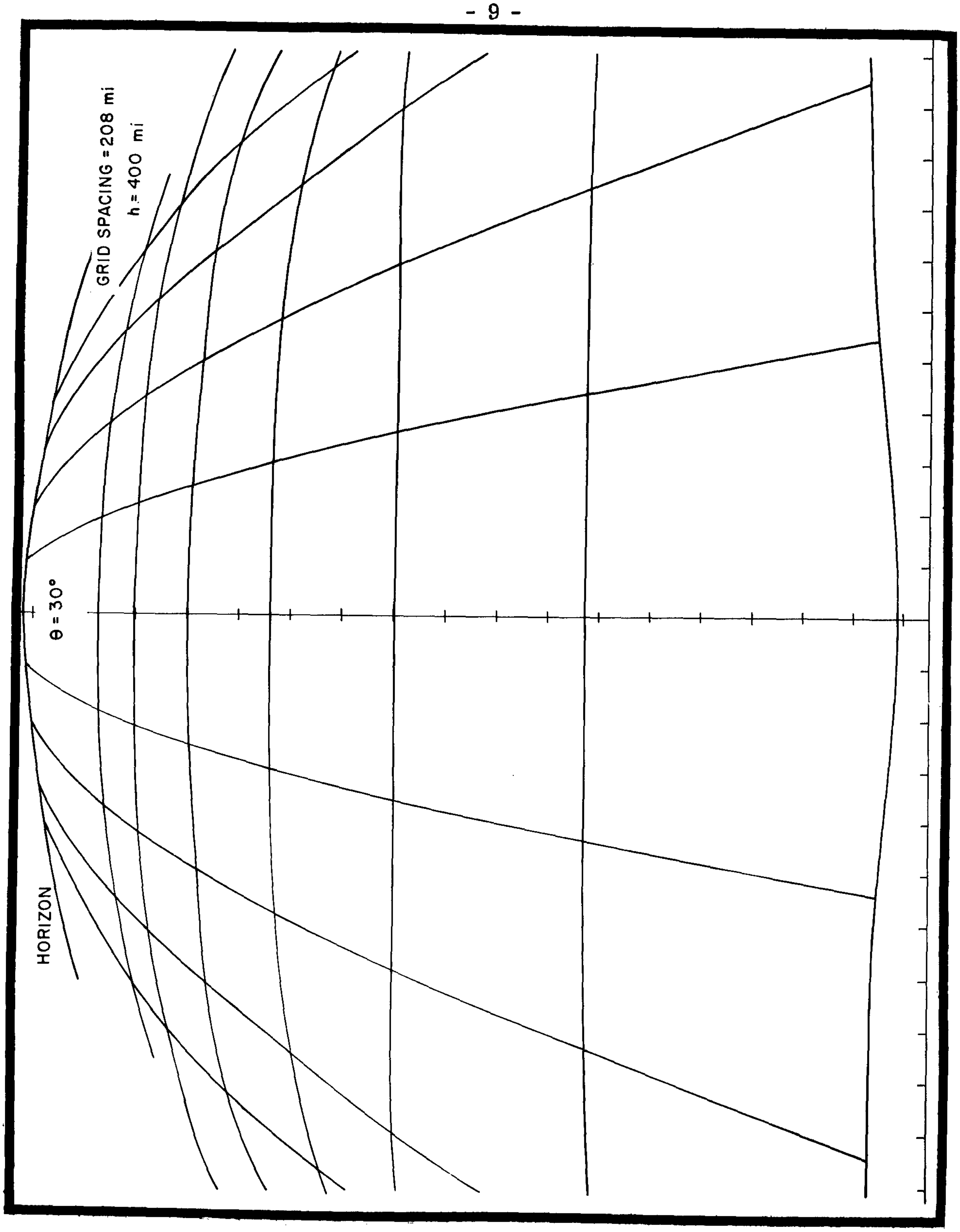


Figure 1.4. Perspective Grid for Rectification of Satellite Images.

limit of our booster capabilities. Assuming a polar orbit, a satellite with a wide-angle lens TV camera (about 100°) would view a strip of the earth's surface about 800 miles wide on each orbit. Each complete orbit would require about 96 minutes, during which time the earth's surface would have moved eastward 24°. Thus, a considerable part of the surface would be missed on each successive orbit as shown by figure 1.5. A nonpolar orbit reduces the area of photographic coverage even more.

1.5 Applications to Weather Analysis and Forecasting

One of the obvious applications of satellite data is in the location and tracking of storms. This aspect has received wide publicity, mostly as a result of a photograph taken from a Navy Aerobee rocket, launched from White Sands, New Mexico. The photograph, shown in figure 1.6, first appeared in an article in the Monthly Weather Review of June 1955 (13) and was later featured in a September issue of Life magazine.

Satellite data should be most valuable in forecasting weather elements related to clouds. They should be instrumental in improving forecasts of clear versus overcast, of general flying conditions, etc. Tropical forecasting, relatively unsuccessful at present, should benefit materially from satellite observations (33).

1.5.1 Conclusions

Most forecasters have a general idea of the physical processes causing various clouds. However, the meteorological significance of these physical processes is not always clear. Meteorological analysis methods must be developed which will make the fullest use of cloud information. Perhaps completely new techniques will be needed in areas where no conventional meteorological data exist.

It seems unlikely that satellite cloud analysis can ever fully replace present observing or forecasting techniques, but it can serve as a valuable supplement to currently available observations, both in well-observed areas and in areas where conventional data is scarce or nonexistent.

1.6 Operational Plan for Meteorological Satellite Project TIROS (NASA Meteorological Satellite)

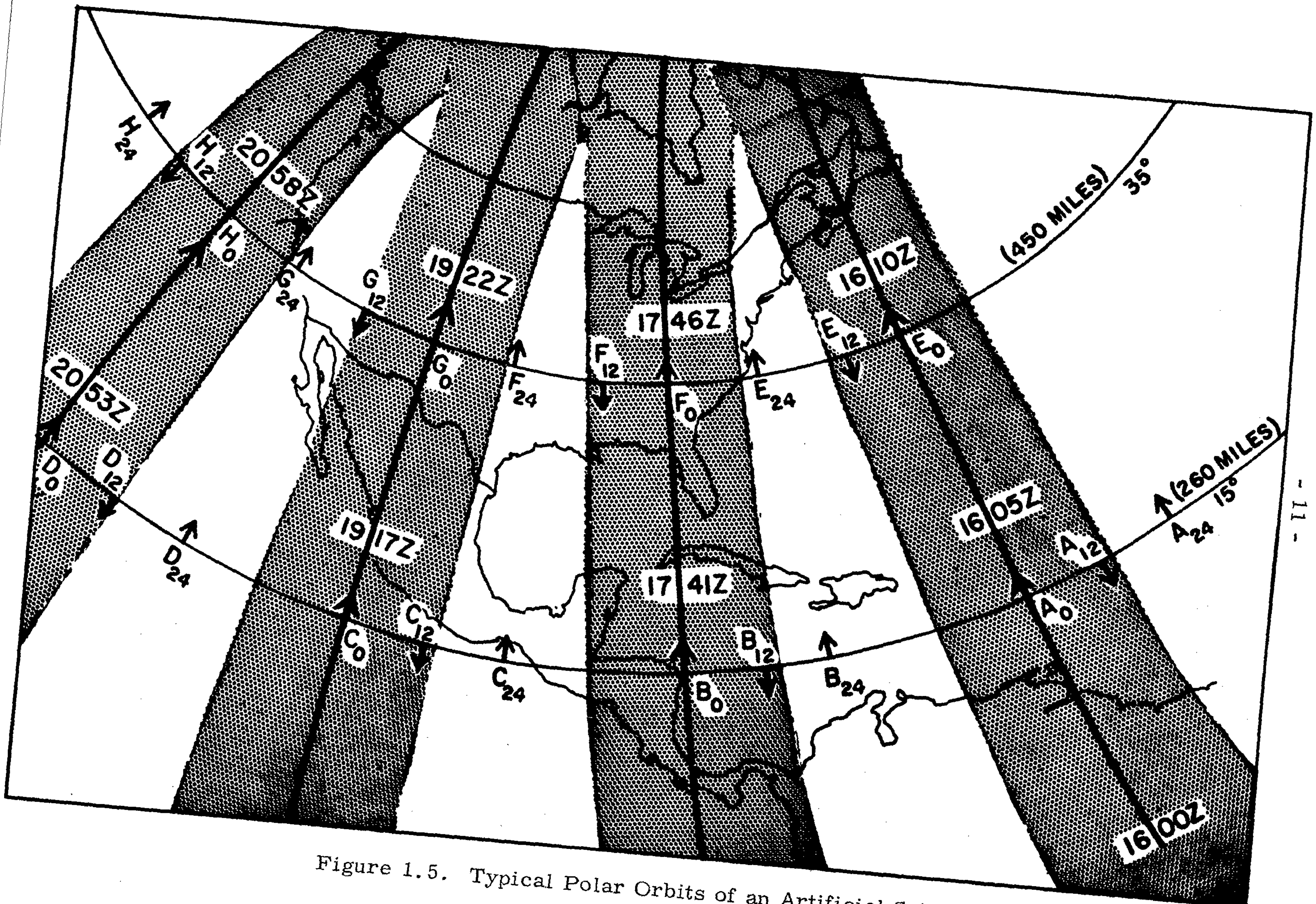


Figure 1.5. Typical Polar Orbits of an Artificial Satellite.

Figure 1.6. Photograph of a High Level Vortex Taken from an Altitude of Approximately 80 Miles.

1.6.1 Configuration, Orbit, and Period

The first meteorological satellite under NASA (National Aeronautics and Space Agency) supervision, planned for launch in 1960, will be in the form of an 18 sided polygon, 19 inches high and 42 inches in diameter, weighing about 270 pounds.

It will be fired from Cape Canaveral on an intermediate circular orbit at an altitude of 400 miles with a period of 99.6 minutes.

1.6.2 Basic Weather Observing Instruments

The basic weather observing instruments will be two recording TV cameras, both axially aligned but differing in coverage and resolution.

1.6.3 Coverage and Resolution

The wide-angle camera will sweep an area approximately 725 miles on a side. A high resolution camera will focus on a smaller area in the center of the larger picture (assuming the optic axis normal to the earth's surface).

1.6.4 Readout of Data

Thirty-two pictures will be stored on magnetic tape during each orbit for playback over the designated ground readout station. Direct link camera readout, bypassing the tape recorder, is possible when the satellite is within radio range.

1.6.5 Tracking and Orientation

Two beacon transmitters with 30 milliwatt outputs are provided in the satellite for tracking by ground stations. Attitude sensors will provide data on spin velocity, sun angle, horizon position, and damping requirements. The satellite will be spin stabilized.

1.6.5.1 Spin Control

The third stage rocket will impart a spin rate of about 135 revolutions per minute (r.p.m.). Upon separation a precision damping mechanism is activated to stabilize the spin, and a 10 minute delay timer

releases de-spin weights which unwrap from the outer surface of the payload, reducing the angular rate from 135 r.p.m. to 12 r.p.m. After de-spin the weights and their trailing wires automatically separate from the vehicle. Angular velocity is then maintained within the limits of 9-12 r.p.m. by firing any of 9 opposing pairs of peripheral rockets on command from the ground station, which constantly monitors the angular rate of the satellite by processing the output of the attitude sensors.

1.6.6 Data Analysis

The U. S. Weather Bureau, as the National Meteorological Service has primary responsibility for data analysis, and a Meteorological Satellite Section for this purpose has been established at the National Weather Analysis Center (NAWAC), Suitland, Md.

The Navy Photographic Interpretation Center (NPIC), Suitland is responsible for developing the TV images received from TIROS and for superimposing overlays on the pictures to show cloud photographs with latitude and longitude lines and other pertinent information.

1.6.7 The Meteorological Satellite Center, Suitland, Maryland

Personnel at the center will be meteorologists from both the U.S. Weather Bureau and Department of Defense (DOD) agencies, principally the Air Force.

They will select the orbits to be read out and supervise the activities of personnel stationed at the ground readout sites.

1.6.8 Primary Command and Data Acquisition Stations

Observed cloud data will be received, recorded, and processed by primary ground stations at Kaena Point, Hawaii and another point in the continental United States yet to be determined.

Meteorologists at the readout sites will be from the U. S. Weather Bureau and DOD agencies. Photographic film from the readout sites will be sent to NPIC for further processing, then forwarded to interested agencies.

Meteorological information will be transmitted to the Meteoro-

logical Satellite Center by the most rapid communications available.

1.6.9 Operational Use of TIROS Data

Pictorial data from the Project TIROS Meteorological Satellite will be made available on film within a very few minutes after telemetered material is received at the data aquisition stations. The objectives of the Immediate Operational Use Program are to abstract useful meteorological information and prepare it in such a fashion that it can be used for practical purposes. Such use depends upon the promptness with which the processed material reaches the hands of the operational forecaster. For this reason precision and scientific objectiveness may be subordinated to the requirements of speed and productivity.

Techniques will be developed for effective utilization of the type of information that can be expected from meteorological satellites. Some difficulties may be experienced in integrating satellite material into normal forecasting techniques because it will not be synchronous with conventional observations, and various parts of the satellite field of coverage will be acquired at different times.

Perhaps one of the greatest gains will be a rational evaluation by the scientific and meteorological community, as well as the general public, of the potentialities of the meteorological satellite as a tool for increasing the scope of observation and improving forecasting. Any contributions that the TIROS satellite may make toward forecasting in any part of the globe will mark a significant step forward in meteorology (32).

A flow diagram of naval participation in Project TIROS is shown in figure 1.7.

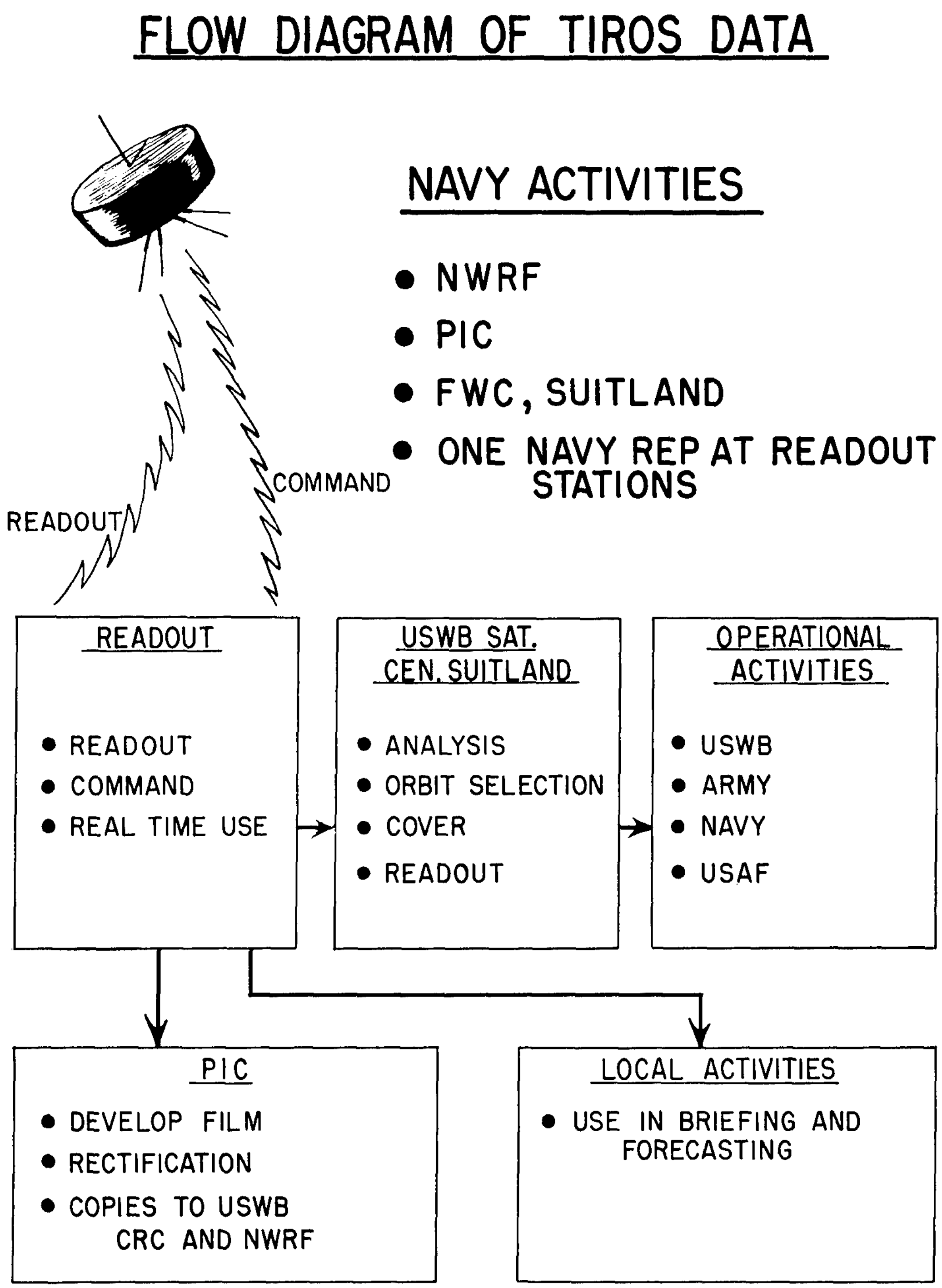


Figure 1.7. Flow Diagram of TIROS Data.

2. RELATIONSHIPS BETWEEN LARGE SCALE CLOUD MASSES AND SYNOPTIC WEATHER FEATURES

2.1 Cloud-Weather Relationships

Since prehistoric times man has noted the relation between clouds and weather. Some of the first studies in meteorology were based on efforts to relate synoptic weather features with clouds and cloud systems. In the early days, before adequate upper-air data became available, cloud observations were the main source of information on the behavior of the atmosphere above the earth's surface. Nephanalysis was qualitative, highly subjective, and considerably dependent on experience. With the increase in quantitative observational data and the development of dynamic meteorology, it fell into disrepute. Although some attempts were made by the French school of nephanalysts to revive it as a forecasting tool, no significant contribution to the literature of this field of meteorology has been made for the past 50 years.

There is abundant literature on the subject of cloud microphysics and numerous manuals on techniques for forecasting some types of clouds, such as cirrus and cumulus, but little or no effort has been directed toward analysis of large scale cloud systems in their relation to the processes which cause weather.

In view of the lack of any presently available techniques for utilizing cloud data from meteorological satellites, it is apparent that considerable research will be needed before the data can be integrated into our present systems of weather analysis and forecasting.

2.1.1 Clouds and Vertical Motion

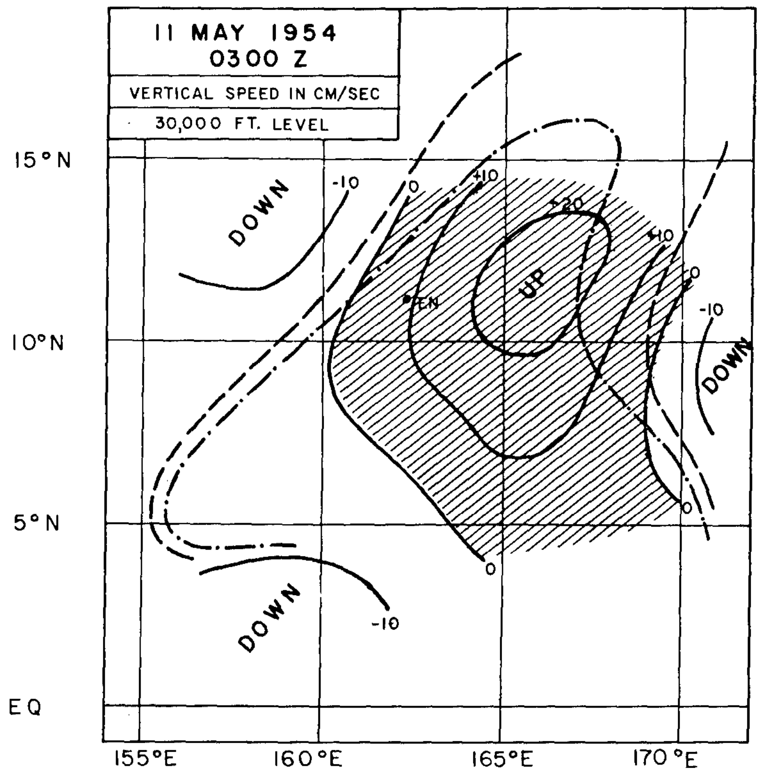
Cloudiness is a function of vertical motion; i.e., upward motion is associated with increasing cloudiness and precipitation, subsidence with improving weather. However, over land, particularly during the summer, there is little relation between large scale weather patterns and vertical motion. Vertical motion is influenced by local features and shows strong diurnal variations, the phase of which may be quite different in different regions (29). Mean annual cloud cover charts plotted for the continental United States show overcast areas on the windward slopes of mountain ranges and clear areas on the leeward side.

Brunt (5) lists the following types of vertical motion which cause cloud formation:

(a) Large scale convection as a result of surface heating.
(b) Turbulent motion leading to numerous small scale upward currents.
(c) Uphill currents over sloping ground.
(d) Currents of warm air moving upward over a wedge of cold air (frontal clouds).

2.1.2 Vertical Motion and Weather

This subject is treated more fully in NWRF 30-0359-024 (Vertical Motion and Weather) (29). Figures 2.1 and 2.2 show the relation



Upward Motion

Edges of Cloud Sheets (Ci, Cs, Cc): ------ greater than 1/8 cover. —·—·—· greater than 5/8 cover.

Figure 2.1. A Comparison Between the Field of Vertical Motion at 30,000 Feet and the Distribution of High Cloud Forms (After Rex).

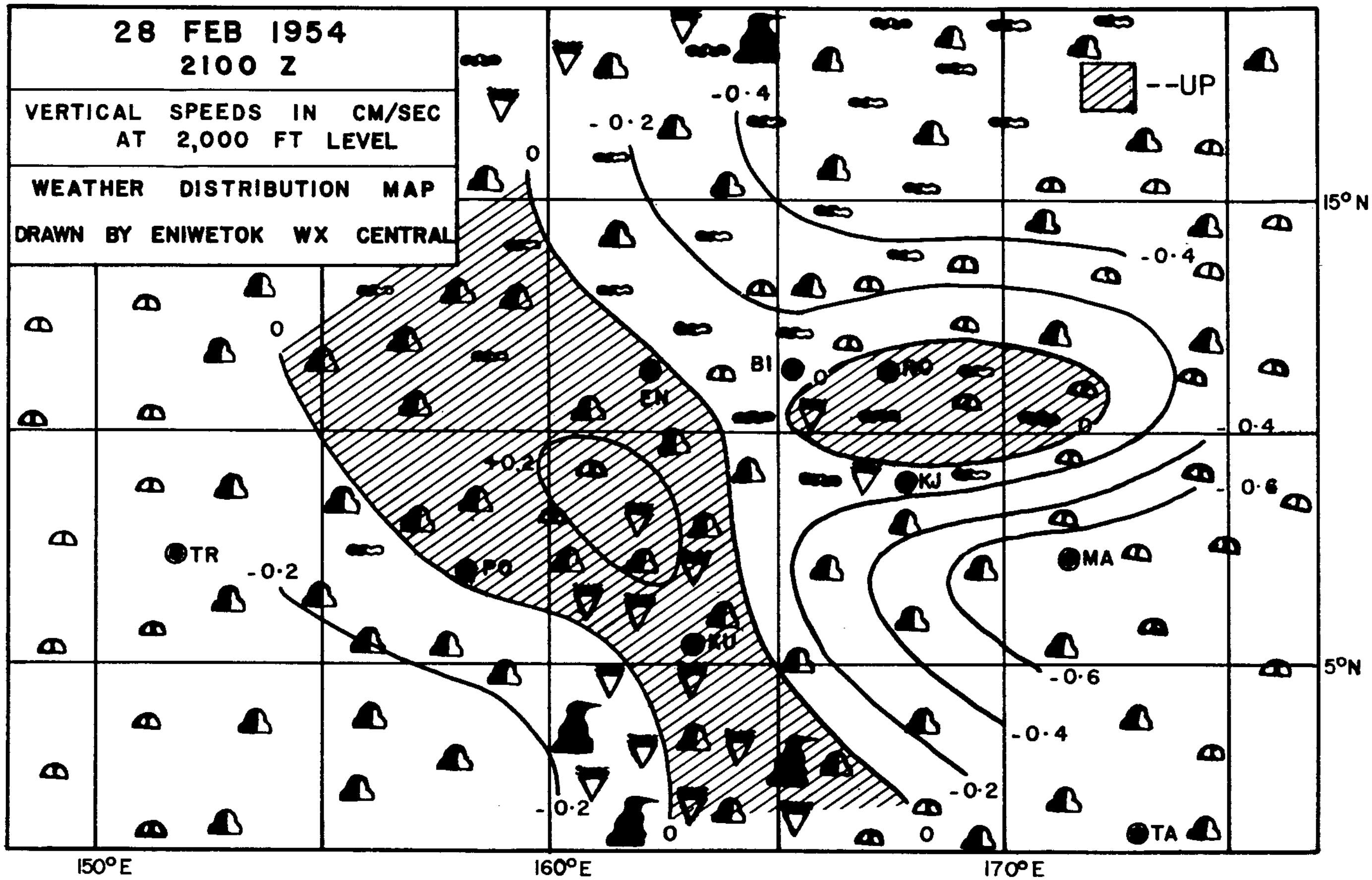


Figure 2.2. A Comparison Between the Field of Motion at 2,000 Feet and the Field of Composition (Cloud and Precipitation Forms). Upward Motion Is Cross-Hatched; Conventional Cloud and Weather Symbols Are Used. (After Rex.)

between vertical motion and cloudiness in the tropics.

TABLE 2.1

Percentage Probability of Various Weather Types as a Function of 12-Hour Average Vertical Motion.

Weather Type	Vertical Velocity, cm./sec.				
	< -1.7	-1.7 to -.6	-.5 to .5	.6 to 1.7	> 1.7
Clear or Scattered	67	55	43	30	9
Broken or Overcast	26	35	42	49	44
Precipitation	7	10	15	21	47

Table 2.1 shows that the probability of occurrence of various types of weather is definitely influenced by vertical motion. For example, with large upward motion the probability of clear or scattered is only 9 percent, whereas it is 67 percent with strong subsidence. Actually, the relation may be even better since the computed vertical motions are not completely accurate (29).

2.2 Cloud Classification

The present cloud classification is essentially the same system proposed in 1803 by Luke Howard (17). It is based mainly on differences in height and appearance.

Glaser (32) has suggested a classification which groups clouds into (a) those characteristic of air masses and their modification (thermodynamic), and (b) those associated with synoptic weather systems (kinematic). Large scale cloud masses would fall into the same groups.

2.3 Cloud Systems

A cloud system is usually thought of as a mass of clouds associated with a single definable feature of the atmospheric circulation. Classical models of cloud systems have been constructed for extratropical cyclones, tropical cyclones, warm and cold fronts, etc. Few cloud systems encountered in nature ever fit this ideal picture, and cloud masses associated with one atmospheric system often merge with those of another.

A pilot study recently conducted by Allied Research Associates (33) indicates that the largest size systems presenting a reasonably coherent cloud pattern (which could be detected by a satellite) are those associated with extratropical cyclones. Larger scale flow patterns could not be clearly delineated. The cloud pattern seems to be most closely related to events in the lowest part of the atmosphere.

2.3.1 Thermodynamic Cloud Systems

Thermodynamic cloud systems result from large scale air mass modification and generally contain but one cloud type in a given area.

2.3.1.1 Cold Air Outbreaks

The leading edge of the cold air may vary from a cloudless area to a wide band of heavy middle and upper clouds. In the cold air behind the front, clouds will generally be of the cumuliform type. The total cloud amount naturally depends upon the amount of moisture present. Over large bodies of water even trivial cold-air incursions may cause widespread stratocumulus.

2.3.1.2 Warm Advection

Warm advection usually results in destabilization of air in the middle troposphere and stabilization in the lower atmosphere. The sequence of cloud forms ranges from flat cumulus at a considerable distance from the warm front to a solid layer of amorphous low clouds, sometimes forming a continuous system with the clouds of the warm front.

2.3.2 Kinematic Cloud Systems

Kinematic cloud systems are dependent upon large scale vertical motion. They usually form a continuous or nearly continuous cloud

mass. The edges of the overcast areas are usually sharp, only a few miles of broken cloud normally separating overcast from clear.

2.3.2.1 Middle Latitudes

2.3.2.1.1 Extratropical Cyclones

Cloud patterns of extratropical cyclones are contained in almost every elementary text on meteorology and should be familiar to any practicing meteorologist.

2.3.2.1.2 Fronts

Radar observations indicate that fronts are not always continuous. Kinematic clouds caused by lifting of warm air at or near the front may be absent or obscured by thermodynamic clouds. In many cases, particularly in the case of an abrupt wind shift, the front will be marked by an abrupt change in cloud type. Experienced forecasters do not need to be warned that all lines and discontinuities do not represent fronts.

2.3.2.1.3 Squall Lines

Squall lines are strong convergence lines occurring in warm air masses ahead of advancing cold fronts. They are usually straight and about 100 to 200 miles long.

2.3.2.1.4 Anticyclones

Large cloud-free areas are almost universally dominated by anticyclonic systems. In the continental United States the center of the clear area is usually slightly southeast of the center of the high with widespread cloudiness, often stratocumulus, at the southeastern edge.

2.3.2.2 Tropical Systems

Because of the scarcity of conventional meteorological data in the tropics, satellite observations should be most valuable in this area. A great deal of photographic data on tropical cloud forms has been obtained from aerial reconnaissance flights, but most of it is from relatively low altitudes.

2.3.2.2.1 Easterly Waves

Easterly waves are troughs associated with perturbations in the tropical easterlies. They occur primarily on the Equator side of subtropical highs of the summer hemisphere and are oriented roughly north-south, reaching from near the center of the subtropical anticyclone to the intertropical troughs.

East of the wave is a zone of convergence, characterized by cumulonimbus clouds and heavy shower activity often extending eastward for 300 miles. The area to the west of the trough line shows considerable divergence with a shallow moist layer so that cloud coverage is usually less than 5-tenths.

Tropical depressions, which may grow to hurricane proportions, sometimes form on easterly waves.

2.3.2.2.2 The Westerly Trough

The cloud distribution about a westerly trough is somewhat similar to that associated with an easterly wave; i.e., towering cumulus and cumulonimbus with heavy showers from the trough line to a distance 150 to 300 miles eastward.

Middle and high clouds extend westward about 150 miles.

2.3.2.2.3 The Shear Line

The shear line is essentially a cold front which has penetrated far into the Tropics. As a rule it is oriented east-west on the equatorward side of a high cell. When the shear is sufficiently strong, it is marked by cumulonimbus, heavy rain, and extensive stratocumulus and altocumulus. Behind the line of shear, cloudiness and precipitation decreases rapidly.

2.3.2.2.4 The Intertropical Convergence Zone

The Intertropical Convergence Zone, formerly known as the "Equatorial Front" or the "Intertropical Front", marks the zone of bad weather found in certain tropical regions where the trade winds of the two hemispheres converge. Width of the zone may vary from 50 to 400 miles and intensity from a few towering cumulus to cumulonimbus

with as many as six layers of altostratus and cirrostratus. Usually, it is most intense when it is some distance from the Equator.

2.3.2.2.5 Tropical Cyclones

The characteristic cloud patterns associated with tropical cyclones are too well known to bear repetition here. Hurricane circulations should be relatively easy to identify, although it may be difficult in some cases to distinguish intense hurricanes from minor tropical disturbances.

2.4 Special Cloud Forms

Some cloud forms which are not usually visible from the surface may be observed from a satellite.

2.4.1 Banner Clouds

These are lenticular type clouds, which may range from stratocumulus through cirrus, forming downwind from mountain peaks. They are almost a permanent feature over high elevations in the Tropics.

2.4.2 Billow Clouds

Billow clouds are broad, nearly parallel, lines of cloud oriented normal to the wind direction and are usually associated with the "mountain wave" effect. Satellite observations may provide a source of much needed data on this phenomenon.

2.4.3 Cloud Streets

The tendency of cumuliform clouds to orient themselves in more or less parallel rows is particularly marked in the tropical trade winds area. This tendency, which has also been observed in radar photographs of hurricanes and extratropical cyclones, appears to be a common feature of all convective phenomena.

2.4.4 Stratospheric Clouds

Normally, the stratosphere is cloudless. Occasionally, however, cloud forms have been observed in this region, and it is likely that these will be considerably more visible from a satellite.

2.4.5 Nacreous Clouds

These thin clouds occur at altitudes of about 16 miles and appear to be composed of water droplets (7).

2.4.6 Noctilucent Clouds

These clouds, which occur at altitudes of 50 to 60 miles, are so thin that from the ground they are visible only when illuminated by the sun while the earth below is in darkness. For this reason they are seen mostly in polar latitudes. They may be composed of volcanic or cosmic dust or even water droplets.

2.4.7 Haze

Haze, while not a cloud formation in the usual meteorological sense, will almost certainly be visible from a satellite and will be, at times, indistinguishable from cloud.

2.4.8 Fumulus Clouds

Fumulus clouds are accumulations of haze which assume characteristic cloud shapes without reaching condensation. They may be indicative of the same processes which cause cloud formation in saturated air.

2.4.9 Jet Stream Clouds

Varying reports of clouds at the jet stream level do not give sufficient information to provide any definite rules on jet stream location from cloud observations.

Where cirrus clouds occur in connection with a jet, they are generally located 25 to 50 miles south of the core and form a ribbon extending along the course of the jet stream.

3. A CASE STUDY - Operational Use of Cloud Cover Data for Weather Analysis Over the North Atlantic, 24 August 1959

3.1 Introduction

The photographic material used in this study is a mosaic made of three frames taken from a stabilized camera in the nose cone of an Atlas missile fired from Cape Canaveral at 1600Z, 24 August 1959. Average altitude was 400 miles (fig. 3.1).

The three photographs were chosen because they show easily

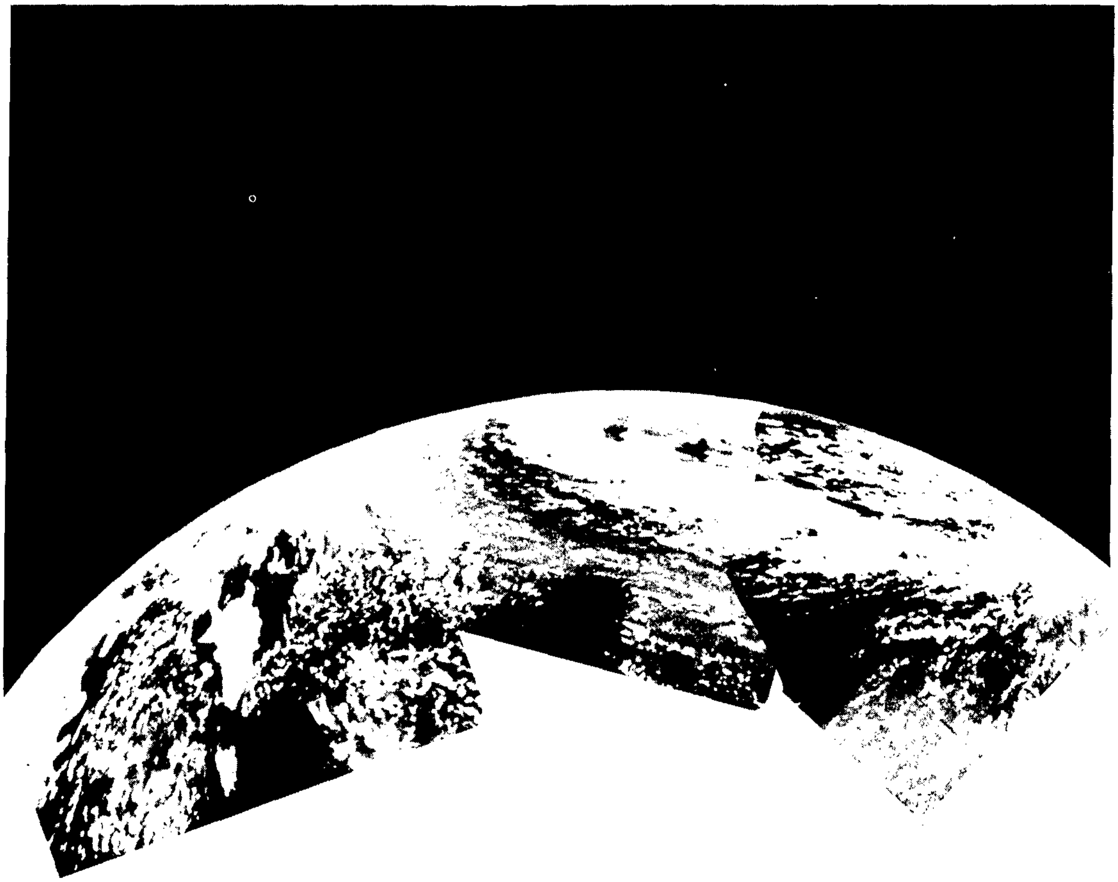


Figure 3.1. Mosaic of Atlas Photographs.

identifiable topographic features which can be used for location and orientation of the significant meteorological features.

The purpose of this study is to demonstrate the immediate operational usefulness of cloud cover data received from a satellite where direct readout is attainable. In this hypothetical case the readout station is a ship operating in the North Atlantic. To make the simulation more realistic we can assume the ship to be an aircraft carrier located south of Bermuda at 1600Z, 24 August 1959, steaming eastward along the 30th parallel at a speed of 15 knots.

3.2 The Cloud Mosaic

The details of the Atlantic coast from the tip of the Florida Peninsula northward make it fairly easy to orient the photograph and locate significant features without employing a grid system.

3.3 Cloud Analysis

The coastline north of Charleston, S. C. merges with a frontal cloud system extending eastward and northeastward across the Atlantic. Identification of cloud type is doubtful but the frontal zone appears to consist of a band of altostratus 150 to 200 miles wide. Two waves are visible on the front, the more intense one, near Bermuda, showing what appear to be cirrostratus or dense cirrus radiating outward from it. The second wave is more difficult to locate precisely, but appears as a bulge in the northeastern portion of the front and a widening of the band of frontal clouds. Both waves appear to have stratified clouds, associated with warm air advection, in the warm sector.

3.4 Synoptic Analysis

The 1800Z surface chart shows a quasi-stationary front extending from the Atlantic coast just north of Charleston, S. C. southeastward to 31° N. 70° W., thence eastward just north of the 30th parallel, curving northeastward near 50° W. Ship reports indicate a wave on the front near 33° N. 46° W. The lack of ship reports in the area between this wave and Bermuda account for omission of the second wave from the preliminary analysis (fig. 3.2). However, a careful reanalysis of preceeding maps and the Bermuda report enable one to place the second wave just east of Bermuda. Analysis of the cloud photograph leaves no doubt as to its existence (fig. 3.3).

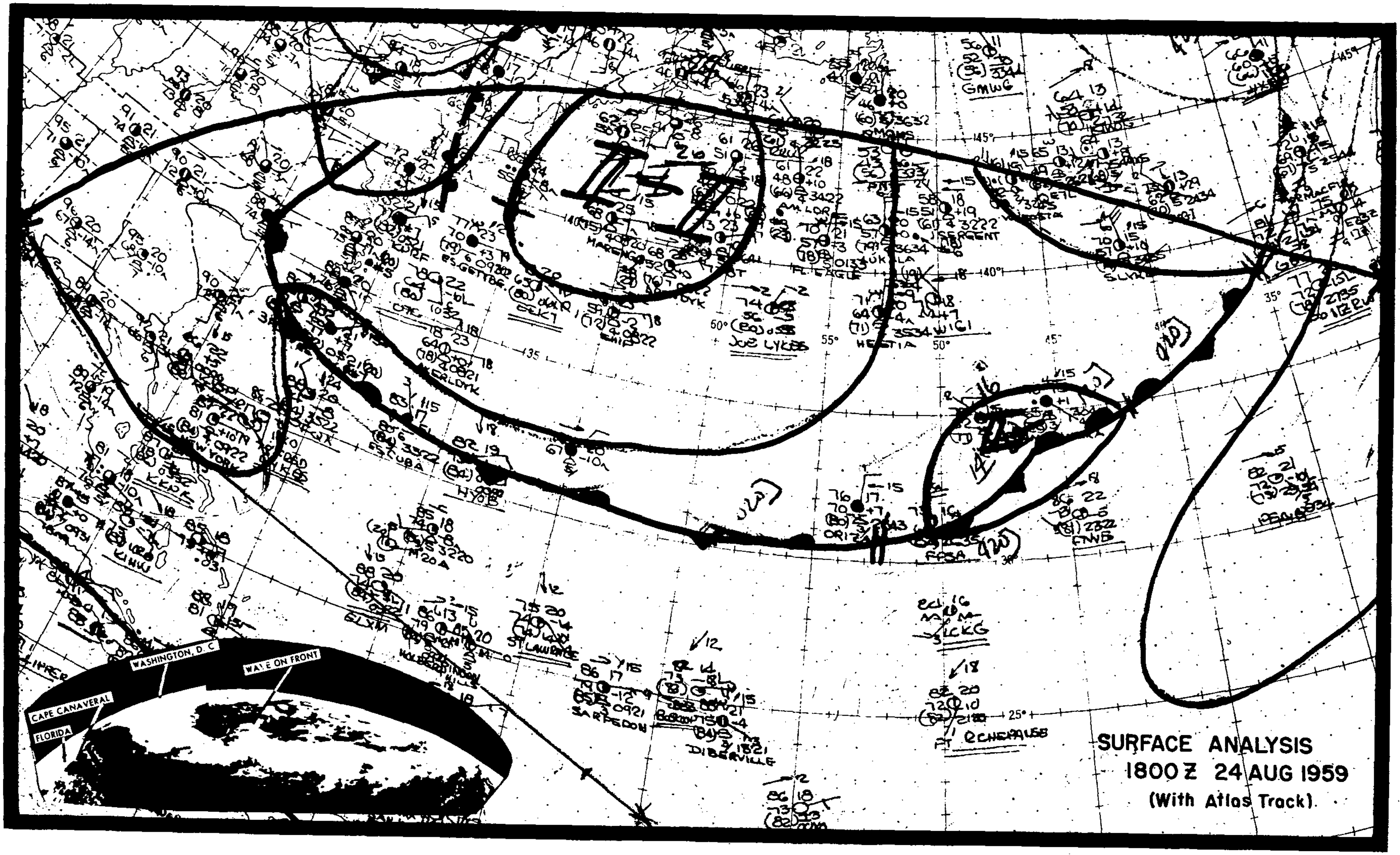


Figure 3.2. Synoptic Analysis 1800Z, 24 August 1959.

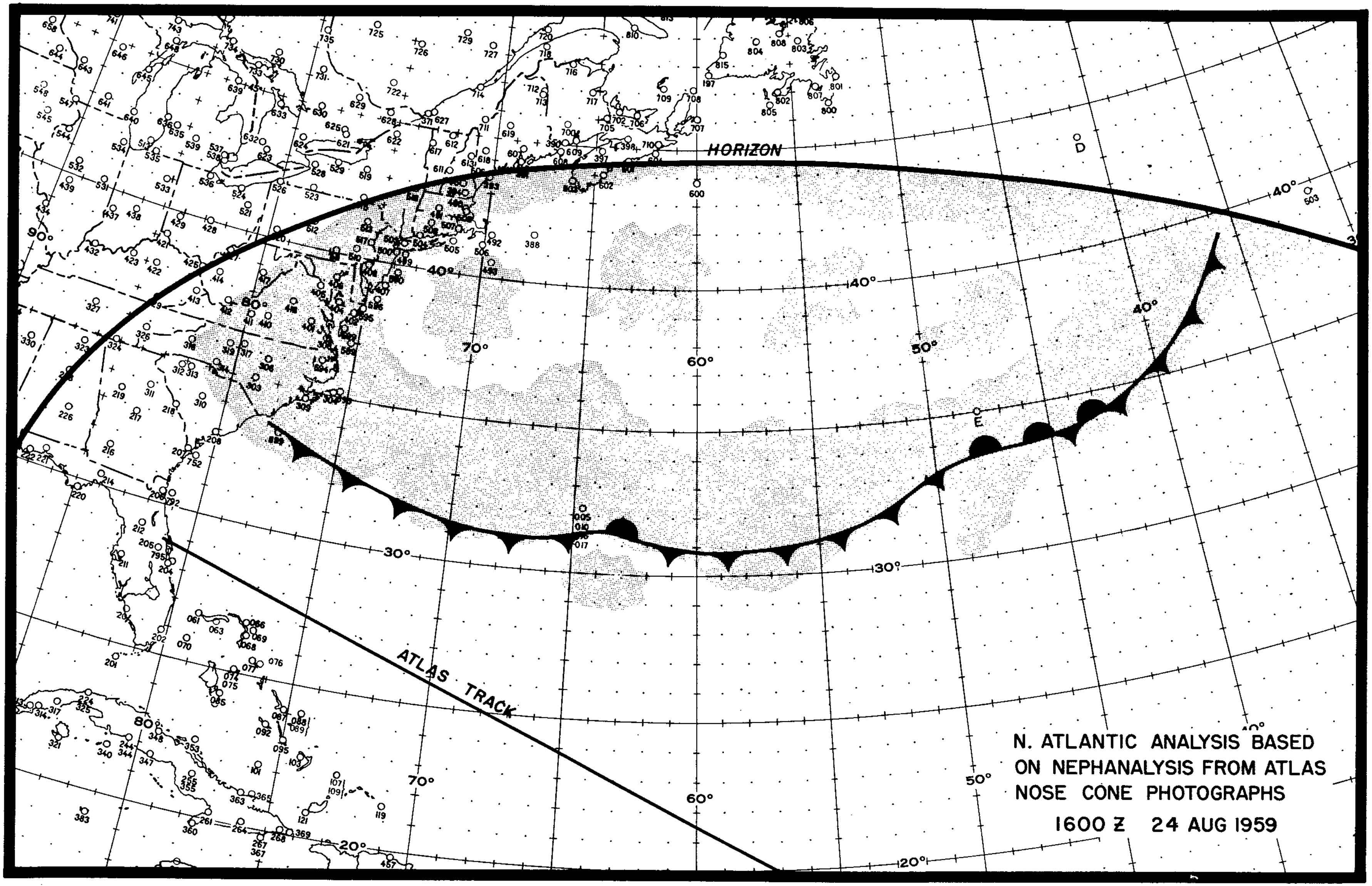


Figure 3.3. Cloud Schematic and Reanalysis of Surface Synoptic Chart.

3.5 Forecasting and Weather Briefing

There is nothing to indicate much southward movement of the cold front. However, one would expect the wave to move eastward along the front with some southward oscillation before it turns northeastward. Upper air data are of little help in forecasting the wave movement because of the scarcity of the data, and pure extrapolation appears to be the only solution. Having placed the front accurately on the basis of the cloud data we can only assume a reasonable speed of advance based on a wind forecast. It may be assumed that the weather officer aboard the carrier might obtain additional information on the location and movement of the front by judicious use of the ship's radar. At any rate, a reasonable estimate would be 15 knots. This would mean the carrier would remain under the frontal cloud shield for at least the next 48 hours, with rain and very poor flying conditions. Altering the track 100 miles south would provide good flying conditions but winds, because of their direction, would be unfavorable for carrier flight operations. In this case the cloud photographs would show this to be the best choice. A photograph of the cloud structure presented to the commanding officer with a regular briefing from the weather map should be very convincing. For pilot briefing such pictures would be an invaluable aid.

3.6 Post Analysis

It should be noted in this hypothetical case that frontal positions were taken from NAWAC surface map analyses, based mainly on ship reports with no substantiating cloud observational data. In actual practice satellite data, ship's radar, and pilot reports could be used to verify these positions.

The forecast position of the wave for 1800Z, 25 August 1959 was in error, but the recommended track, as shown in figure 3.4, would have been well south of the frontal zone. Succeeding positions of the wave were essentially as forecast, so that the recommended track would have placed the ship in an area of favorable weather conditions for at least the next 4 days.

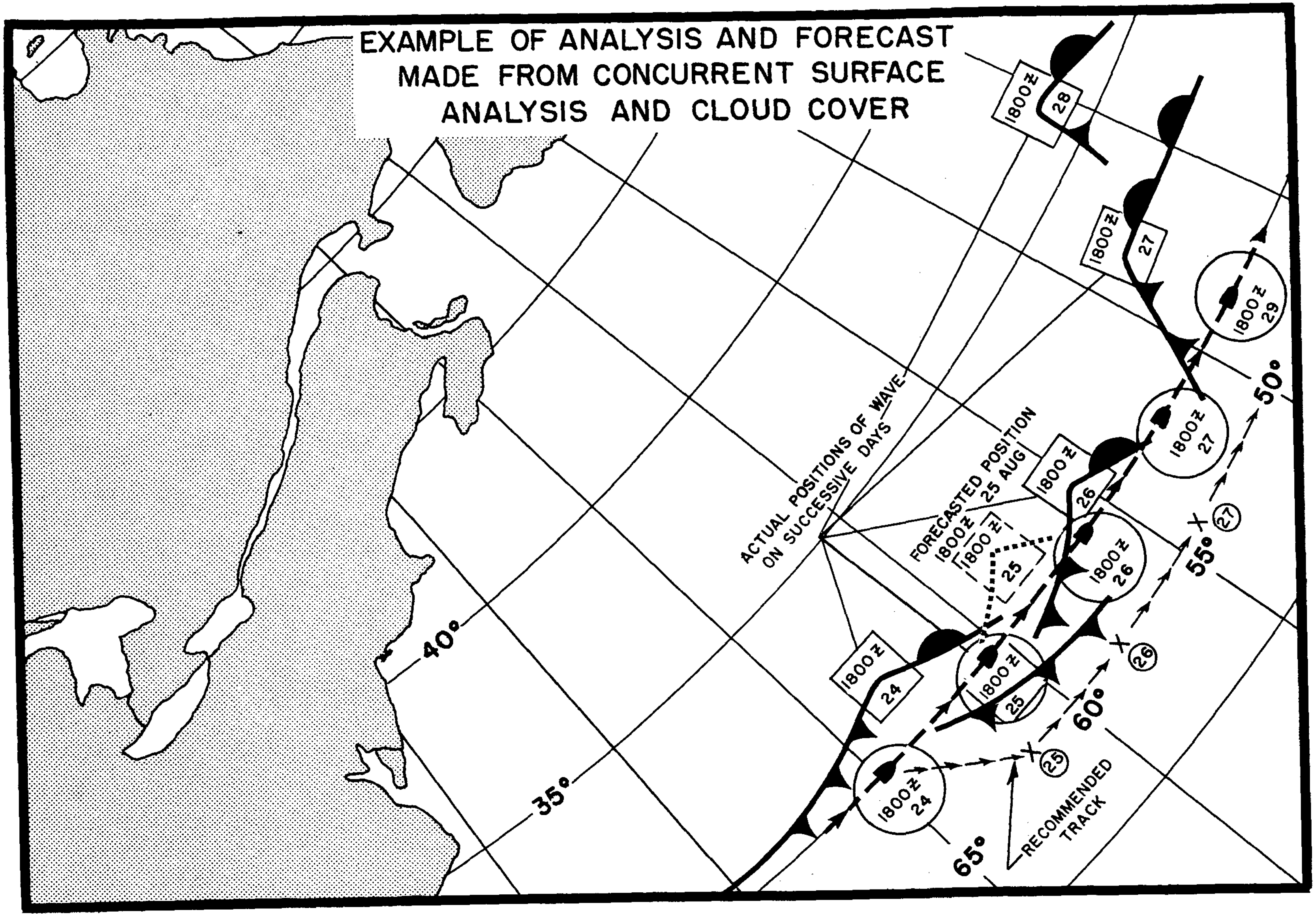


Figure 3.4. Analysis and Forecast from Concurrent Cloud Data and Surface Synoptic Analysis.

4. CONCLUSIONS AND RECOMMENDATIONS

This study may be criticized as being unrealistic in that it employs data which may not always be synchronous with surface observations or over areas where it can be utilized. The answer is that aircraft carriers usually do operate in the area selected for this study and that a satellite in a polar or intermediate orbit at an average altitude of 400 miles would almost certainly provide data at such times and places as to make it operationally useful, if direct readout aboard ship ever becomes feasible. Increased satellite altitude would provide a greater area of coverage, but other factors would limit the usefulness of the data. The case cited merely shows what can be done with the limited data which is now available or will be available in the near future. The Navy, because it does operate in relatively small isolated units which are critically dependent upon weather, often in areas where weather information is not available from normal sources, is probably more interested in immediate operational use of satellite data than are civilian or other military agencies.

4.1 Limitations of the Present Civilian Meteorological Satellite System (TIROS)

4.1.1 Transmission of Data

Present limitations both as to wavelength and location of tracking stations allow transmission only when the satellite is within line of sight of the receiving station.

Readout of data after each orbit is desirable for two reasons:

(a) Meteorological data is extremely perishable.
(b) Size and weight limitations restrict the storage capacity.

Direct readout by major ships and Fleet Weather Centrals would eliminate the processing and transmission delays which limit the usefulness of satellite data.

4.1.2 Nature and Quality of Data from TIROS

Observational data from TIROS will consist of cloud photographs which will be considerably inferior in quality to those used in this study.

Photography will be possible only during daylight or, occasionally, in bright moonlight.

4.1.3 Problems of Image Distortion, Rectification, Resolution, and the Inability to Photograph

Clouds at night or with low sun angles will seriously limit the effectiveness of TV cameras in TIROS. This limitation can be lessened by choosing a polar orbit.

4.2 Recommendations

It seems fairly obvious that cloud observations from satellites can furnish a useful tool to the forecaster. Most forecasters have a general idea of the physical processes associated with various cloud forms, but considerably more research will be needed on the relationships between cloud masses and synoptic weather systems.

Satellite photography may make possible a much needed global cloud atlas of continental and oceanic areas. This would show normal cloud patterns associated with major weather systems and should show seasonal and diurnal variations. It seems unlikely that the resolution to be expected from satellite TV pictures will permit identification of cloud types, but a catalogue of cloud masses associated with climatic patterns would be most useful.

More information is needed on the optical properties of clouds. A knowledge of directional properties of cloud reflectivity and of internal cloud features that influence reflectivity is needed for designing appropriate satellite systems.

Most important, new techniques must be devised for fullest use of cloud information. Minute and detailed nephanalysis will not be possible. The difficulties of integrating such information are comparable to those experienced with weather radar systems which have been in operation for some time. But little effort has been directed toward fullest utilization of this information in present techniques of weather analysis and forecasting.

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